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AN OUTLINE OF THE GEOLOGY OF NEW ZEALAND[1]

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Pre-Silurian.—In the more recent accounts of the history of New Zealand it has been customary to consider as of Pre-Cambrian age the complex of gneisses and associated metamorphic rocks in the southwestern extremity, but the evidence for so doing is not yet conclusive, and various authors have referred the plutonic gneisses therein to different periods, extending as late as the Cretaceous. It would appear that the more probable hypotheses could be limited to two.

The first definite point lies in the proved existence of Lower Ordovician rocks in the extreme northwest and southwest of the South Island (Fig. 1).[2] These graptolitic slates are associated

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[1] This outline is based on the writer's presidential address delivered to the geological section of the Australasian Association for the Advancement of Science in 1921. For detailed discussion of the most recent work, with full bibliography, reference may be had to this address. Earlier extensive accounts have been given by Marshall ("New Zealand and the Adjacent Islands," Steinmann's *Handbuch der regionalen Geologie*, Bd. VII, Abt. 1, 1912), and Park (*The Geology of New Zealand*, Whitcombe and Tombs, 1910).

[2] The map herewith (Fig. 1) has been based upon one recently issued by the Geological Survey (see *New Zealand Journal of Science and Technology*, 1921) and also incorporated in the above-mentioned address, thanks to the generous permission of the director of the geological survey, Mr. P. G. Morgan. The present copy has been somewhat modified in accordance with the view favored herein concerning the age of the Otago schists, etc.

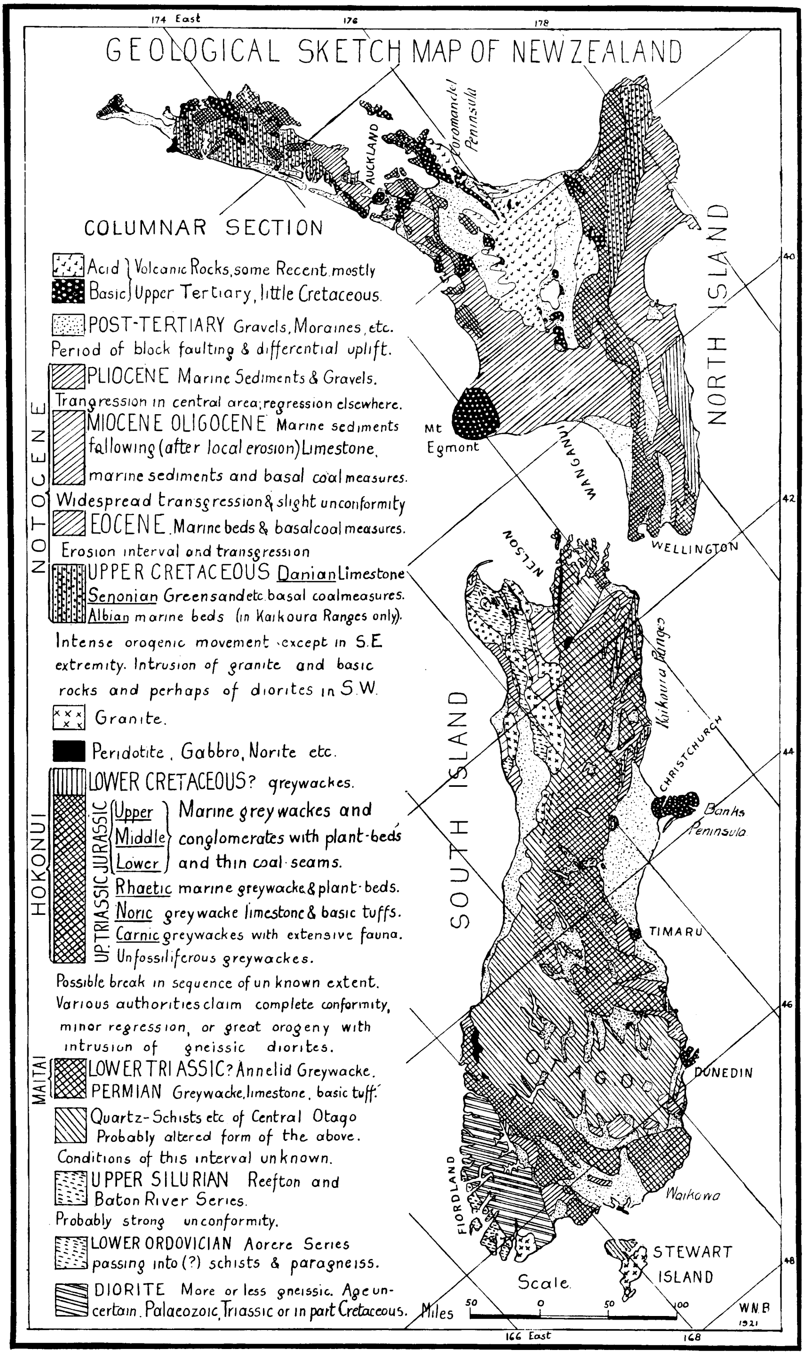
GEOLOGICAL SKETCH MAP OF NEW ZEALAND
174 East
176
178
COLUMNAR SECTION
Acid } Volcanic Rocks, some Recent, mostly
Basic } Upper Tertiary, little Cretaceous.
POST-TERTIARY Gravels, Moraines, etc.
Period of block faulting & differential uplift.
PLIOCENE Marine Sediments & Gravels.
Transgression in central area; regression elsewhere.
MIOCENE OLIGOCENE Marine sediments
following (after local erosion) Limestone,
marine sediments and basal coal measures.
Widespread transgression & slight unconformity
EOCENE. Marine beds & basal coal measures.
Erosion interval and transgression
UPPER CRETACEOUS Danian Limestone
Senonian Greensand etc. basal coalmeasures.
Albian marine beds (in Kaikoura Ranges only).
NOTOCENE
Intense orogenic movement except in S.E.
extremity. Intrusion of granite and basic
rocks and perhaps of diorites in S.W.
Granite.
Peridotite, Gabbro, Norite etc.
LOWER CRETACEOUS? greywackes.
JURASSIC Upper } Marine greywackes and
Middle } conglomerates with plant-beds
Lower } and thin coal seams.
UP. TRIASSIC Rhaetic marine greywacke & plant-beds.
Noric greywacke limestone & basic tuffs.
Carnic greywackes with extensive fauna.
Unfossiliferous greywackes.
HOKONUI
Possible break in sequence of unknown extent.
Various authorities claim complete conformity,
minor regression, or great orogeny with
intrusion of gneissic diorites.
LOWER TRIASSIC? Annelid Greywacke.
PERMIAN Greywacke, limestone, basic tuff.
MAITAI
Quartz-Schists etc of Central Otago
Probably altered form of the above.
Conditions of this interval unknown.
UPPER SILURIAN Reefton and
Baton River Series.
Probably strong unconformity.
LOWER ORDOVICIAN Aorere Series
passing into (?) schists & paragneiss.
DIORITE More or less gneissic. Age uncertain. Palaeozoic, Triassic or in part Cretaceous.
AUCKLAND
Coromandel Peninsula
NORTH ISLAND
Mt Egmont
WANGANUI
WELLINGTON
NELSON
Kaikoura Ranges
CHRISTCHURCH
Banks Peninsula
SOUTH ISLAND
TIMARU
OTAGO
DUNEDIN
FIORDLAND
Waikawa
STEWART ISLAND
Scale
Miles 50 0 50 100
40
42
44
46
48
166 East
168
W.N.B.
1921

FIG. 1

Correction: Insert ? after "Erosion interval" between EOCENE and UPPER CRETACEOUS in section above.

with limestones, graywackes, and quartzites and pass with apparently gradual transition into mica-schists, which are invaded by gneissic diorites. A narrow zone of such schistose rocks extends intermittently down the west coast of the island. In the southwest the gneissic diorites become dominant and are associated in one region with "granitic" gneisses. In addition, there are massive plutonic rocks, chiefly granites, occurring especially in the two extremities of the island and surrounded by zones of contact metamorphism, which is naturally more marked where the regional metamorphism is least pronounced. The first hypothesis is that adopted by the Geological Survey. The gneissic rocks and invaded schists are considered to be of pre-Ordovician, possibly pre-Cambrian age, and covered unconformably by the Ordovician sediments. No sharp line of separation has, however, been found between them, nor other evidence of difference of age, such as the inclusion of gneissic pebbles in the Ordovician rocks. The massive plutonic rocks are considered to be of much later date, and probably later Paleozoic or even in part Mesozoic.

The second hypothesis regards the more or less gneissic dioritic rocks as having invaded the Ordovician sediments in Paleozoic or possibly Mesozoic times, before or during the climax of an orogenic movement, while the intrusion of the massive plutonic rocks followed after that climax. Within the present year massive diorite has been found to invade Lower Triassic (?) annelid-bearing graywacke. In a variant of this hypothesis advocated by Park, the subordinate mass of "granitic" gneiss is held to be intensely altered sedimentary rocks and regarded as probably pre-Ordovician, merging upward into Ordovician slates. The abundance of sillimanite in the gneiss accords with this view. Petrographical examination of the gneissic diorites on Grubenmann's principles, first applied hereto by Speight, indicates that they form the core of a folded range, for structures characteristic of deep-seated metamorphism are found in the center of the massif, while those produced at lesser depths occur on either side.

Bartrum has found that pebbles of similar metamorphic rocks are widely distributed in the Mesozoic and Cainozoic rocks of the North Island, suggesting the existence of an ancient Paleozoic platform beneath the younger formations. Their occurrence also supports the hypothesis that the dioritic rocks are not younger than early Mesozoic.

Silurian.—The fossiliferous Silurian strata are known in two localities only, both in the northwest of the South Island. They strike in a direction usually about north-northwest, the same as that of the Ordovician rocks, but their relation thereto is as yet unknown, nor are the conditions at all favorable for investigating this. In the northern of the two areas (Baton River) the rocks are calcareous argillites, but in the southern occurrence (Reefton) they are of more littoral and varied nature, with a consequent difference in faunal facies. Both faunas are apparently closely related to the Upper Silurian (Wenlock) faunas of Southeastern Australia, but have not yet been very critically examined.

"Permo-Carboniferous" and Lower Mesozoic.—No further information is available until the close of the Paleozoic era, when commenced the more nearly continuous portion of the stratigraphical record. The greater part of the mountainous country of New Zealand is made up of steeply folded and shattered argillites and graywackes, generally devoid of fossils. They contain, though rarely, lenticular masses of limestone, and also, especially in the upper portions intercalated plant beds. Widespread basic tuffs, etc., occur in the lower portion. On one higher horizon basalt flows are present. Numerous subdivisions and groupings have been proposed for this series, and Trechmann's recent paleontological work, supported by that of Arber, Wilckens, and Boehm, seems to place on a firmer basis than formerly the division of the complex into a series of formations ranging from Permian to early Cretaceous age.

Permian.—The oldest fossiliferous rocks seem to rest conformably on an extensive series of basic breccias, which are probably coeval with similar breccias which elsewhere rest unconformably on Silurian rocks. The fossiliferous beds, limestones, and argillites contain at one locality (near Nelson) a few poorly preserved shells and corals which have been compared with Eastern Australian Permo-Carboniferous (Permian) forms. Among these is a large, indefinite myalinid shell which was referred doubtfully to *Inoceramus* and more recently to the Australian Permian form *Aphanaia*, though probably both comparisons are erroneous. Fragments of this shell, however, are widespread throughout the South Island of New Zealand, and in default of better evidence may be used to indicate the extent of Permian rocks. These are succeeded by a great thickness of graywackes in which an annelid tube is almost the sole indication of organic life. Jaworski considers this form indicative of a Triassic age. It is perhaps remarkable that there are no traces of plant beds known among these rocks. *Glossopteris* does not occur in New Zealand, though a form occurring in Upper Triassic and Jurassic beds was for a time doubtfully referred to this genus.

Triassic.—There is no clear evidence (beyond that mentioned above) of a great break, accompanied by plutonic intrusions, between the Permian and Triassic fossiliferous strata, though this has been assumed by some authorities. Probably, however, a regression of the sea occurred during Middle or Lower Triassic times, as in New Caledonia. The oldest fossiliferous Mesozoic sediments are referred to the close of the Middle Triassic, and are succeeded by fossiliferous Upper Triassic rocks, representatives of the three divisions of the Alpine-Himalayan Upper Trias, Carnic, Noric, and Rhaetic being recognizable, and each divisible into subzones. The fauna is Tethyan, with the interesting addition of the circum-Pacific form *Pseudomonotis ochotica.* In general the succession of Upper Triassic faunal zones is very similar to that of New Caledonia. The local absence of well-marked horizons gives evidence of crust-warping during Upper Triassic times, and there is a notable development of basaltic tuffs and lavas among the Noric rocks. The alternation of graywackes and argillites, and intercalation therewith of plant beds or conglomerates, indicate that these sediments were formed on a continental shelf. The flora of the region, which has been studied by Arber, was similar to the contemporaneous Australian flora, but the total number of species known in the Mesozoic rocks of New Zealand is only about a quarter of those known in Australia.

Jurassic and Early Cretaceous.—These general conditions of sedimentation were maintained during the Jurassic period, in which, however, the plant-bearing beds became relatively more abundant in the South Island, and thin coal seams occur. Lower (Liassic), Middle (Bajoccian), and Upper (Tithonian) Jurassic marine faunas are recognized, and a sequence of small floras also, but the detailed description of the first two has not yet appeared.[1] There are also a series of sediments which are rather widespread in the east of the North Island, and are perhaps of early Cretaceous age, but may be in part Upper Jurassic. They contain *Inoceramus* in some abundance. In the western side of the island, the Jurassic rocks are followed conformably by early Cretaceous (Neocomian) plant beds, containing two angiosperms.

Orogeny.—The orogenic movement which succeeded this long-continued sedimentation reached its maximum in Lower Cretaceous time. The Mesozoic sediments were forced into broken or overturned folds, and zones of shattering were produced. The axis of such folding is for the most part approximately meridional and generally oblique to the much later warpings and fault-lines which determine the northeasterly trend of the present mountain system. Plutonic intrusions occurred in connection with this folding, among which are a series of masses of ultrabasic and basic rocks appearing at intervals from end to end of New Zealand. They are most noteworthy near Nelson in the north of the South Island, where is the type-locality of the rock dunite. The association of such intrusions with fault-zones is sometimes clear. In addition to these are granites and syenites especially well developed in the northwest of the South Island, but it is as yet problematical how much of the more or less gneissic plutonic rocks of the southwestern region should be referred to this series of intrusions. Among the minor intrusions of this period are a restricted series of lamprophyric dikes, monchiquites, etc.

Undetermined schists.—We may here describe one of the most puzzling formations in New Zealand, a broad zone of mica-schists running to the southeast from the main mountain range, through the Otago province of the South Island. These have for the most part a very flat position, but dip to the southwest and northeast of the broad anticlinal axis, which reaches the sea near Dunedin. To these rocks all ages have been assigned from Archaean to Jurassic. They are not associated with plutonic rocks, but may be traced outward from a central zone of maximum schistosity, through gradually decreasing metamorphism into graywackes indistinguishable from the Ordovician or Lower Mesozoic graywackes. The Geological Survey and the majority of other authorities hold that the schists are ancient and must be separated by obscure disconformities from the Mesozoic rocks. Marshall considers the schist Mesozoic, and, after much hesitation, the writer inclines toward a modification of this view. In this it is suggested that the flat arch of metamorphic rocks is the base of a great series of recumbent folds of late Paleozoic and Lower Mesozoic rocks which were pressed against a resistant or continental mass now concealed beneath the southern portion of the island. In the front of such a series of recumbent folds one would expect to find a sharp fourfold-wrinkle of the crust, beyond which the thrusting would die away in gentle undulations of the strata lying on the resistant mass. Within the overfolded areas, block-faulting might bring down the comparatively unmetamorphosed rocks of the higher recumbent folds into close apposition with the more schistose rocks of the lower folded sheets (Fig. 2). These expecta-

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[1] Trechmann and Spath have described this fauna since this paper was written. See *Quart. Journ. Geol. Soc.*, 1921.

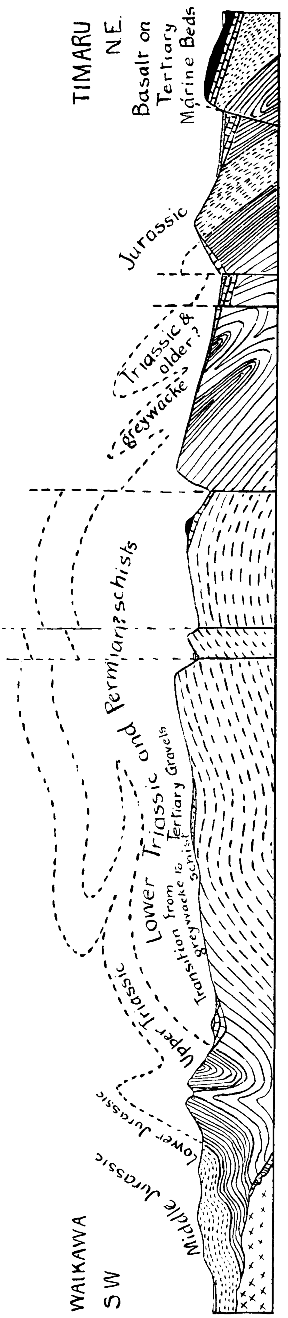
TIMARU
N.E.
Basalt on Tertiary Marine Beds
Jurassic
Triassic & older? Greywacke
Permian? schists
Lower Triassic and Permian? schists
Tertiary Gravels
Transition from greywacke to schist
Upper Triassic
Lower Jurassic
Middle Jurassic
WAIKAWA
SW

FIG. 2.—Hypothetical section from Waikawa to Timaru across the broad "anticline" of Otago. Length, 180 miles

tions appear to be realized in some measure in the facts observed in field study. The microscopical structure of the schists is indicative of strong lateral thrust rather than static metamorphism, and an excellent series of gradational structures which link them with the graywackes has been obtained by Marshall. Moreover, the apparent absence from the graywackes of any material which seems to have been derived from the schists is a striking feature, considering their close association.

The "Notocene" Sediments.—The record of the later Cretaceous and Tertiary times has as elsewhere received diverse interpretations. The simplest among current views considers that the whole series is conformable throughout. Overlap on to an evenly subsiding but irregular surface accounts for the difference of age of the basal beds in different regions. The period of greatest submergence was the period when limestone was deposited, so that the limestones in all regions must be considered as of the same age. They are succeeded by beds of a clastic character, indicating the return of shallower conditions. On other hypotheses the whole group of formations is divided up into several unconformable series, but the ages assigned these series, and the horizons at which the unconformities were recognized, have been different in the statements of different writers, or at different times in the statements of one writer. While, therefore, there has been little dispute as to the succession of strata in any region, the history of the whole period throughout New Zealand has remained obscure.

Two new conceptions have been advanced during the last decade. Thomson has suggested the existence of "diastrophic provinces," i.e., regions throughout each of which the tectonic history has been the same, though differing from that of adjacent regions. On this hypothesis, the difference of age of basal beds depends on the overlap of formations on a subsiding uneven bed but also on the different periods at which subsidence commenced in the various provinces. The limestones are not necessarily coeval throughout New Zealand, but represent merely the rock formed at the time or times of maximum submergence in each particular province, for in some districts more than one horizon of limestone is present. So also the regression of the sea occurred at different times, and the highest beds in one province may not be coeval with those in an adjacent province. There is no need to consider that any unconformities or disconformities of a general nature are present, though local breaks may occur. Thomson has, moreover, suggested the convenient term "Notocene" (the "Southern New" formation) to indicate the whole group of sediments laid down between the Lower Cretaceous orogenic period and that which, occurring possibly at the close of Pliocene time, ushered in the present physiographic cycle.

The areal work of the officers of the Geological Survey has given rise to the second conception. Block-faulting and tilting of the crust, which was so extensive a process of the post-Notocene (Pleistocene?) orogeny, was not confined thereto, but occurred at intervals from Middle Cretaceous times onward. The movements were chiefly vertical, but along fault-planes the strata may be much crushed or upturned. Erosion proceeded *pari passu* with elevation, and the beds laid down after such movements may rest with apparently perfect conformity on the undisturbed areas, but with small or great unconformity where lying on the eroded surface of a tilted block, or near a fault-plane, or they may cross, without disturbance a zone of fault-breccias in the underlying Lower Notocene rocks (Fig. 3). If these two conceptions be admissible, we have the explanation of much apparent conflict of evidence seen when we attempt to correlate the stratigraphical succession in various regions. We must also note that such generalizations as are in the columnar statement on the map herewith must be subject to modification in detailed application to special areas.

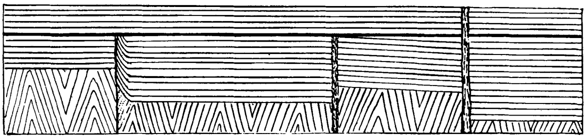

FIG. 3.—Diagram illustrating the conception of a general but deceptive conformity obscuring an erosion-interval in the deposition of "Notocene" rocks.

Later Cretaceous.—The earliest of the Notocene incursions of the sea entered a small part of the northeastern portion of the South Island in Middle Cretaceous times, flooding a very irregular surface. Sixteen species of fossils have been recognized by Woods in the deposits of this period, forms identical or allied with species typical of the general Indo-Pacific fauna of the period. What follows is not quite clear, but probably the sea retreated, and entered again in late Cretaceous times, covering a much more extensive area and submerging other portions of the northeast and also in the southeast of the South Island and the east and northern portions of the North Island. A much more extensive fauna was introduced than before, over sixty species being known, which, according to Woods, Trechmann, and Wilckens, are of the typical Indo-Pacific Senonian types, with a particularly marked affinity with the fauna of Southern America and Grahams Land. Indeed, it seems as if we must conclude that New Zealand, Antarctica, and South America lay, at the close of Cretaceous times, on the coast of the South Pacific Ocean, involving the hypothesis of a land connection at this period between these regions, a conclusion to which biologists have long tended.[1] In some parts of New Zealand the Senonian beds are followed by a great thickness of almost unfossiliferous though partly foraminiferal limestone, to which a Danian age has been assigned. This stage is, however, missing from many districts.

Eocene.—In "Eocene" times,[2] the sea spread in certain regions, but was missing from others. Three contrasted developments of beds of this epoch may be noted. At this time were formed the most valuable coal-measures in New Zealand, those in the northwestern portion of the South Island, the recent survey of which has been in large part due to Morgan. The highlands adjacent to this region were still unreduced, and a great thickness of conglomerate was laid down prior to the formation of the coal-measures, which in turn are succeeded by marine mudstones, the fossils of which contain less than 5 per cent of recent forms. On the other hand, in the southeastern portion of the South Island, the Upper Cretaceous coal-measures are succeeded by soft mudstones or impure limestones, which Marshall found to contain less than 10 per cent of Recent forms in rather extensive faunas, including also some characteristic early Tertiary genera. In the northeastern part of the South Island a series of marly rocks overlying the abovementioned Danian limestone may represent this epoch.

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[1] There is very little affinity between the Cretaceous faunas of New Zealand and Australia.

[2] The Lyellian terminology may perhaps be retained for the major subdivisions of the Notocene period, but since we do not know the relative rate of evolution of new marine forms in New Zealand and Europe, we cannot conclude that strata with like percentages of Recent forms in the two regions are coeval, and hence the terms based on such percentages can have but a local comparative value. For this reason the convention is adopted of placing them between quotation marks.

Oligocene and Miocene.—By the close of "Eocene" times the mountains formed during the Cretaceous crust-folding had been reduced approximately to a peneplain, and the marine transgressions of "Oligocene" and "Miocene" times submerged the greater portion of the South Island, and much of the North Island, and a very rich molluscan fauna was present. There was, however, considerable local variation in the development of such marine rocks, a discussion of which would necessarily lead into much detail, with the difficulties of conflicting correlations and a confused nomenclature. It should, however, be noted that in the central region of Otago in the South Island, where, it is suggested, the recumbent folds of the Cretaceous orogeny were most highly piled, reduction by erosion and subsidence seems to have been retarded, so that this region remained above the level of the Tertiary sea, but in "Miocene" and perhaps also in "Pliocene" time was largely covered with fluviatile and lacustrine deposits, often richly auriferous.

Pliocene.—Crust-warpings at the close of "Miocene" times caused the sea to retreat from the greater part of the South Island, though it transgressed on to its northeastern angle. The North Island, however, was largely if not completely submerged, except for the great volcanoes which now commenced their activity. In this transgressive sea "Pliocene" beds were laid down, in some cases with quite noticeable unconformity upon "Miocene" beds. One district calls for special mention, that of Wanganui in the southwestern portion of the North Island which must surely become a classical district for the study of later Tertiary marine rocks in the Southern Hemisphere. A nearly continuous line of sea cliffs exposes a thickness of 3,500 feet of gently dipping clay stones. No break is seen in the succession, nor any sign of faulting, though two carbonaceous layers indicate temporary land-surfaces. Large collections of shells were made by Marshall and Murdoch at four different horizons. In the lowest were 61 per cent of Recent forms; in the next 76 per cent; in the next 90 per cent; and in the highest 93 per cent. Sands containing only modern shells rest with obvious unconformity upon this series, an almost dramatic conclusion to the Tertiary record.

Middle Tertiary faunas.—The marine faunas of Middle Tertiary times in New Zealand contain many new immigrant forms and show signs of South American influence, which scarcely are sufficient to indicate coastal connection at this time, though the affinity of the New Zealand fauna with that of South America is greater than that with Australia. Moreover, since the Middle Tertiary period New Zealand appears to have been entirely isolated.[1] The modern marine fauna is but a diminished residue of the Middle Tertiary fauna, and its specific and generic distinctness from Australian forms precludes a connection of these areas in "Pliocene" and post-"Pliocene" time.

Vulcanism.—During the Notocene period there was considerable volcanic activity. Its earliest manifestation was in a few Middle Cretaceous basaltic eruptions in the northeastern portion of the South Island, and rhyolitic extrusions, to the east and west of Christchurch, which are probably Upper Cretaceous. There are also west of Christchurch some post-Jurassic, pre-Senonian andesites, the relations of which are now being investigated. The products of early and middle Tertiary activity are much more important and widespread. Economically the most important among these were the andesites and dacites[2] of the Coromandel Peninsula, North Island, in which post-magmatic solutions have developed great auriferous deposits. Rhyolites also occur in this complex. Somewhat later were the eruptions of basalt, etc., which formed Banks Peninsula, described by Speight, and the basalts and varied alkaline rocks about Dunedin, which Marshall has studied. In Upper Tertiary times volcanic activity broke out in the center of the North Island, where it has continued to the present time. Andesites, and more or less pumiceous rhyolites, are the chief products of this activity, the principal centers of which are arranged on a line following the northeasterly "grain" of the country. Mount Egmont, the great isolated cone in the west of the island, also consists of andesite.

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[1] It is of interest to note in this connection that characteristic genera of modern New Zealand plants are represented among the Tertiary fossil leaves in Grahams Land.

[2] Included with the basic volcanic rocks in map herewith.

Pleistocene diastrophism.—The period which followed the cessation of Notocene sedimentation, though comparatively short, was that during which New Zealand assumed its present form as a result of a great series of differential movements, warping or tilting of crust-blocks, and the denudation of the surface so produced. The nature of these processes has been elucidated by Cotton. The boundaries of the several blocks are now marked by fault-scarps in homogeneous structures, or by faulted contacts of older and younger strata, at which the latter are often steeply upturned. Usually the faults are oblique to the strike of the folded strata they truncate, and very frequently extend in a northeasterly direction. The movement was not all due to simple tension and differential subsidence of blocks, but strong compressive lateral thrusts also occurred, with the occasional production of folding passing into faults, of overthrusting and even overfolding (Fig. 4).

> The faults present the following characteristics. The movement even along the same dislocation, may be concentrated in a single fracture with walls close together, or perhaps several chains apart, the intervening space being filled with comminuted rock. Again the fault may be a shear-zone. . . . .
>
> One type of fault constantly recurs: narrow trough-faults in which the rock between the main fault-walls belongs to a higher horizon than the walls themselves. When the Tertiary beds which overlie the more ancient sediments and graywackes are involved, the recognition of this type of fault is very easy. [Henderson.]

The surface of New Zealand at the close of the Pleistocene orogeny was thus that of a group of variously elevated earth-blocks composed usually of hard graywacke or schist, on the more or less planed surface of which rested much less resistant Tertiary and sometimes Cretaceous sediments. In many elevated blocks the hard basement rocks rose to a higher level than the comparatively weak covering strata in the adjacent relatively depressed blocks, which formed broad, fault-bounded, intermontane basins or narrow, rectilinear rift valleys, or fault-angle valleys. A consequent drainage was soon established on the broken sheet of covering rocks, which it commenced to remove. Where this process is still incomplete, topography is controlled in large measure by the variation in the resistance to erosion offered by the different strata in the covering rocks, and dip slopes and scarps are characteristic features of the scenery. Where, however, erosion is more advanced, portions of the planed surface of the underlying rocks are laid bare, and where the cover is cleared away from extensive areas, a stripped peneplain is exposed, the further reduction of which is very slow (Fig. 5).

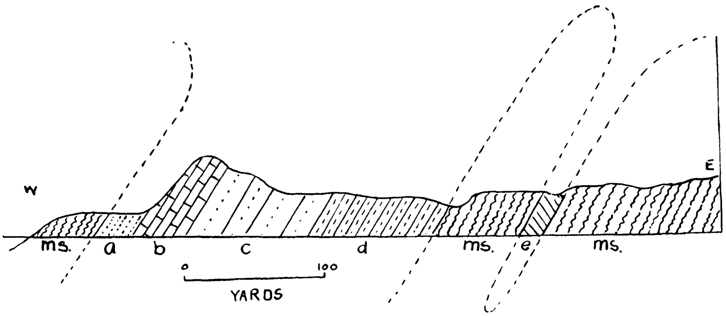

FIG. 4.—Section at Lake Wakatipu showing extensive movement in the post-Tertiary orogeny. *a*, sandstone and conglomerate; *b*, limestone; *c*, marly sandstone; *d*, marly clays; *e*, brecciated Tertiary marine rocks; *m.s.*, mica schist. (After Park.)

Late erosion.—An enormous amount of detritus results in the stripping of the covering strata from the surface of the elevated blocks and from the dissection of the fault-scarps. This is only exceptionally removed as it is supplied. In most places deep aggradation of the troughs has taken place concurrently with the dissection and degradation of the higher blocks.

As a result of this double process many interesting features have been produced in the development of the topographic forms and especially valley systems on this complex land surface. In some regions, especially those composed of the older pre-Notocene rocks, the control of the drainage by structural features is indicated by the reticulated plan of the valley systems, the association of valleys with marked lines of faulting, or with zones of fault-breccias. This is especially noteworthy where narrow masses of the softer covering strata have become involved in the fault-zone, but some control of drainage by fault-zones may be observed even in regions in which the soft covering rocks only are exposed. Probably not only the somewhat reticulate character of the valley systems in the argillites, etc., of the northeast of the South Island has been thus influenced, but also the rectilinearly branching valleys which now form the fiords traversing the gneisses, etc., of the southwestern portion of the same island. Some of the more open, though still long and narrow depressions may be due, not merely to the differential erosion of a strip of soft material among harder rocks, but even to actual trough-faulting. The disposition of the covering rocks about one lake (Te Anau) in the southwest of the South Island affords proof of such in this particular instance.

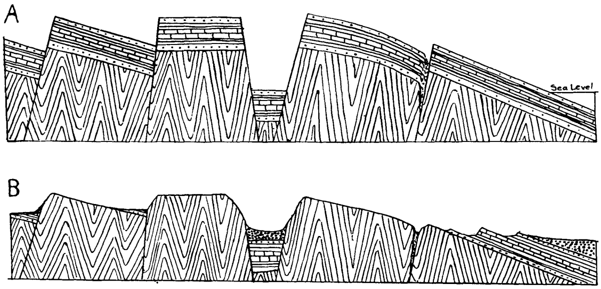

FIG. 5.—Diagram to illustrate the evolution of the present topography. *A*, effect of block-faulting of region covered by weak "Notocene" sediments; *B*, modern topography resulting from denudation of above surface and aggradation in the troughs.

Glaciation.—The topography does not, however, depend actively on structure and normal differential subaerial erosion, for the effects of glaciation are also evident. It seems clear, however, that this was restricted to the highlands and the valleys among them reaching sea-level only along the west coast of the South Island. The ice did not advance to form a large confluent piedmont glacier beyond the eastern slopes of the Southern Alps, though it deployed into sheets of considerable area in the lake basins and associated depressions, notably that of the above-mentioned Lake Te Anau. The view that an ice sheet extended to the low southeastern portion of the island does not appear to be acceptable. As a result of glacial erosion, the valleys in the mountainous portions of the South Island, though originally determined as explained in the previous paragraph, have since been considerably modified. The topographic features characteristic of glaciation have been developed, and there are even indications of the effects of more than one cycle of mountain glaciation. It is not clear what extent of glaciation may have been present in the North Island, but there seems to have been little if any.

In the rain shadow of the Southern Alps an area of very small precipitation occurs in the center of the province of Otago, and here topographic features characteristic of semi-aridity may be seen.

Piedmont aggradation.—Concurrently with the degradation of the mountains, there has been much sedimentation, forming piedmont plains. A series of gravels formed during the elevation of the Southern Alps have been unconformably covered by the gravels of the Canterbury Plains. These consist of a great sheet of detritus over 130 miles long and 30 miles wide, the confluent fans of the rivers draining the eastern slopes of the mountains, at the foot of which they rise to a height of 1,000 feet above sea-level, but they have been built out over a sea floor which has subsided at least 600 feet during their formation. Less extensive plains of gravel and alluvium occur in other districts, each with special features of interest.

Loess.—Of lesser importance are the deposits of loess along the central portion of the eastern coast of the South Island. The loess is composed of the rock-flour carried by the dominant northwesterly winds from the dried pools in the braided valleys of the glacier-fed streams, and has accumulated to a depth of 20 feet or more in suitable situations. Bones of the moa are found in these deposits.

Recent movements.—Since the epoch of great differential displacements of relatively small earth-blocks, which was the essential character of the "Pleistocene" orogeny, there have been a series of relatively small movements involving much larger earth-blocks, which movements have been elevation, depression, or tilting. Exceptionally localized differential movement has resulted in fault-coasts or strongly warped surfaces. Between these movements were long periods of crustal stability during which the cycles of erosion reached a fairly advanced stage. Hence along the coast in different districts there are marked raised beaches, while extending far up the valleys are rock-benches or alluvial terraces, indicating that the valleys are not monocyclic but were rejuvenated from time to time.